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A microeconomic perspective

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Abstract

This article presents a microeconometric analysis of household car use in France. To feature car use dependence, the myopic and rational addiction models are estimated using panel data drawn from the French "Car Fleet" survey. Significantly, the assumption of rational addiction to car use cannot be rejected, and is even supported by a plausible estimate of the intertemporal rate of substitution (17%). Furthermore, the rational model yields realistic estimates of the fuel cost- and income-elasticities of household car use, respectively −0.23 and +0.10 for the short run, and −0.37 and +0.16 for the long run.

Keywords: Household car use, Rational Addiction, GMM, Elasticities.

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1. Introduction

Currently, the contribution of human activity to climate change and the related ecological issues are recognized, and a large international consensus has emerged about the urgency for making economic growth cleaner. In France, policymakers have set environmental targets to converge towards a more sustainable development, as shown by the energy law voted in 2005 by the French Parliament, which aims at dividing the 1990 national level of greenhouse gas emissions by 4 by the year 2050. To reach this objective, a particular effort in the transportation sector is deemed essential. Not only would attention be paid to the volume of emissions, but the perspectives of global peak oil and oil scarcity plead for the necessity to find new and/or more efficient ways to travel, as they should entail an increase in fuel prices in the future. Thus, the question of car use intensity emerges, given that current technology is mainly based on fossil resources. In a context of highly volatile and increasing fuel prices, it is of great importance to understand and to quantify to what extent households adapt their behaviors in terms of car use. Moreover, drivers can be viewed as constituting a "club" whose advantages have grown with their number, leading to a worsening of the social marginalization of non-driving persons. Indeed, a car provides users with a larger control of space and time, and allows a better accessibility to jobs, leisure places, health care, public amenities, etc. However, car users might develop some kind of automobile dependence in order to achieve their mobility, insomuch that several authors go so far as to compare car use to the consumption of tobacco or drugs.[1]

In this article, we propose a microeconometric analysis of the annual mileage traveled by French households with their personal cars. In the literature, this mileage is sometimes referred to as household "automobility", and we will use both expressions interchangeably throughout this paper. The analysis is achieved using the sample of households participating in each of the annual waves of the French "Car Fleet" survey from 1999 to 2001. This period is characterized by peak fuel prices in 2000. It has led households to adjust their car use behavior substantially, thus making fuel cost-elasticities of household automobility easier to measure accurately. Moreover, the panel layout of the data enables us to use dynamic specifications and to derive short and long-run effects. To feature the dependence of households on car use, the myopic and rational addiction models (Becker et al. 1994) are investigated. By applying these models, generally used to describe the consumption of cigarettes, alcohol or drugs, the addiction hypothesis regarding car use can be tested from the microeconomic point of view. To our knowledge, this article provides the first application of the rational addiction model to describe car use behavior, while "automobile dependence" is a major topic of research in transportation economics. The rest of the article is fashioned as follows. Section 2 presents the theoretical framework: the rational addiction model and its properties are examined. Section 3 discusses the econometric specifications and the estimation method. Section 4 provides a description of the 1999-2001 French "Car Fleet" panel dataset. Section 5 reports and debates the estimation results. The last section concludes.

[1] As Dupuy (1999) and Wickham (2002), for example.

2. Microeconomic Framework

2.1. The rational addiction model

In the literature dealing with habit formation, pioneering contributions considered individual preferences to be endogenously determined, assuming that the current utility level depends on past consumption levels (Gorman 1967, Pollak 1970, Ryder and Heal 1973). In this framework, individuals are said to be myopic, since they totally ignore the effect of their current consumption on their future utility. In other words, individuals are making their choices period after period, disregarding the habit-forming property of consumption. Becker and Murphy (1988) argue against the myopia hypothesis of individual behaviors, and have come up with the rational addiction theory, in which individuals are forward-looking agents and aware that consumption is habit forming. In line with Iannaccone (1986), this theory describes an individual as "addicted" to a good if, all else equal, an increase in their past consumption yields a rise in their current consumption. The rational addiction model derived in Becker et al. (1994) examines the behavior of an individual, whose current utility U depends on the consumption amounts of two goods: a quantity X_t of a composite good X, and a quantity C_t of an addictive good C. The current utility also depends on a set of individual characteristics related to life-cycle and summarized by e_t. The addictive and composite goods are different in that current utility also depends on the previously consumed quantities of C. According to the authors, these quantities are accumulated into an addictive capital stock S_t, which is supplied at each current period by the past level of consumption C_{t-1}, so that $S_t = C_{t-1} + (1-\tau)S_{t-1}$. The most commonly used expression to define this stock of habits assumes a complete decay from a period to the next one ($\tau = 1$), thus writing $S_t = C_{t-1}$. At period $t = 1$, let the rational individual look to maximize their discounted utility over an infinite lifetime horizon. Their program is given by:

$$\max \sum_{t=1}^{\infty} B^{t-1} \cdot U(C_t, C_{t-1}, X_t, e_t), \tag{1}$$

where $B = (1+\rho)^{-1}$ is the discount factor, and is the intertemporal rate of substitution. In addition, it is assumed that the interest rate of the economy is equal to ρ, and that the composite X is the equivalent of the money with a price conventionally set to 1. Maximization of the individual's utility is subject to an initial condition regarding the addictive good, and the individual is bound by the intertemporal budget equilibrium:

$$C_0 = C^0 \,;\, A_1 = \sum_{t=1}^{\infty} B^{t-1}(X_t + P_t C_t), \tag{2}$$

where A_1 is the net present value of the individual's wealth, and where P_t is the price of the addictive good at date t. Let the utility function be concave and quadratic, and such as:

$$\begin{aligned} U(C_t, C_{t-1}, X_t, e_t) \quad = \quad & \alpha_C C_t + \alpha_S C_{t-1} + \alpha_X X_t + \alpha_e e_t \\ & + \frac{\alpha_{CC}}{2} C_t^2 + \frac{\alpha_{SS}}{2} C_{t-1}^2 + \frac{\alpha_{XX}}{2} X_t^2 + \frac{\alpha_{ee}}{2} e_t^2 \\ & + \alpha_{CS} C_t C_{t-1} + \alpha_{CX} C_t X_t + \alpha_{Ce} C_t e_t + \alpha_{Xe} X_t e_t. \end{aligned} \tag{3}$$

Under the previous hypotheses, the optimal demand function for the addictive good is derived from solving the maximization program of the individual. It is found to be a function of the nearest past and future consumptions, the current nominal price P_t and the characteristics e_t:

$$C_t = \delta C_{t-1} + \delta B C_{t+1} + \delta_1 P_t + \delta_2 e_t, \tag{4}$$

$$\text{where } \theta = -((\alpha_{CC}\alpha_{XX} - \alpha_{CX}^2) + B(\alpha_{SS}\alpha_{XX}))^{-1}(\alpha_{XX}\alpha_{CS}). \tag{5}$$

For α_{CS} strictly positive, the past and current consumptions of C are said to be complementary. In that case, the current marginal utility of the addictive good, say U_C, is an increasing function of C_{t-1}:

$$U_C = \frac{dU}{dC_t} = \alpha_C + \alpha_{CC}C_t + \alpha_{CS}C_{t-1} + \alpha_{CX}X_t + \alpha_{Ce}e_t. \tag{6}$$

The higher the level of C_{t-1} and the value of α_{CS}, the higher the marginal utility of the addictive good. By analogy with the learning-by-doing, the individual draws all the more utility from the consumption of the addictive good as they "practiced" it in the near past, and as the "learning speed" α_{CS} is high.

The intertemporal complementarity of the consumptions of C is the origin of addiction. It implies $\theta > 0$ in (5). The larger the value of θ, the greater the level of addiction. It can be noticed that the static and autoregressive consumption models are particular cases of the dynamic demand function (4). For $\theta = 0$, the demand function neither depends on past nor on future levels of consumption, and the static case emerges. When $\theta > 0$ and $B = (1+\rho)^{-1}$ drops to 0 (that is, for an infinite preference for the present), the demand function (4) takes the form of a first-order autoregressive process. In that case, the individual is not a forward-looking agent. Becker et al. (1994) defines such a behavior as myopic addiction. In any other situation where θ and B are strictly positive, the addiction behavior is said to be rational. As both these parameters can be estimated, it is possible to determine which formulation is the most relevant from the empirical perspective.

2.2. Elasticities in the rational addiction model

Without loss of generality, let model (4) be rewritten as:

$$C_{it} = \theta C_{it-1} + \theta B C_{it+1} + X_{it}\beta + \varepsilon_{it}, \tag{7}$$

where the subscript i identifies the individual, and X is now a set of exogenous covariates which includes the price for the addictive good. The error term ε summarizes all the unobserved factors from the modeler's point of view.

The impacts on the current consumption resulting from a variation in the past and future consumptions can be deduced from the characteristic roots of the homogeneous equation of (7). These are given by:

$$\varphi_1 = \frac{1-\sqrt{1-4\theta^2 B}}{2\theta}\ ;\ \varphi_2 = \frac{1+\sqrt{1-4\theta^2 B}}{2\theta}. \tag{8}$$

In (8), φ_1 and φ_2^{-1} measure the effect on C_t induced by a shift in C_{t+1} and in C_{t-1} respectively. The elasticities in the rational addiction model can be expressed as functions of these characteristic roots. Let X_k denote the k^{rd} continuous covariate of X, and β_k the related parameter in model (7). The short- and long-run elasticities of the demand for C with respect to X_k evaluated at the sample averages $\overline{X}_k$ and $\overline{C}$, and respectively denoted e^{SR}_{C/X_k} and e^{LR}_{C/X_k}, are given by (Becker 1996, p.113):

$$e^{SR}_{C/X_k} = \frac{\beta_k}{(\theta(1-\varphi_1)\varphi_2)} \times \frac{\overline{X}_k}{\overline{C}}, \tag{9}$$

$$e^{LR}_{C/X_k} = \frac{\beta_k}{(\theta(1-\varphi_1)(\varphi_2-1))} \times \frac{\overline{X}_k}{\overline{C}}. \tag{10}$$

It can be noted that the elasticities resulting from the myopic addiction model logically emerge as particular cases of (9) and (10), for $\varphi_1 = 0$ and $\varphi_2^{-1} = \theta$. The elasticity that stems from the static demand equation, which is the same in both the short and the long run, arises for $\theta = 0$.

2.3. Testing for rational addiction

Testing the rational addiction theory has been performed on various data that pertain to different topics of research. Many applications dealt with drug consumption to tackle public health issues. For instance, Baltagi and Griffin (2001), Becker et al. (1994), Gardes and Starzec (2002), and Tiezzi (2005) used addiction models to explain the consumption of tobacco. Grossman et al. (1998), Bentzen et al. (1999) and Baltagi and Griffin (2002) applied them to model the demand for alcohol. Van Ours (1995), and Grossman and Chaloupka (1998) tested the relevance of addiction models to explain the consumption of opium and cocaine. However, as mentioned by Becker and Murphy (1988), there is no need to express a biological dependence to be considered as addicted to a good. There are other areas of application than tobacco or drug consumption. For instance, Mobilia (1993) tested for addiction to gambling, Cawley (1999) focused on the consumption of calories, Villani (1992) dealt with addiction to art, Cameron (1999) and Sisto and Zanola (2005) applied addiction models to the demand for cinema. To our knowledge, the rational addiction model has not been applied so far to describe car use, while "automobile dependence" is a major topic of transportation research. However, it is advisable to be cautious when interpreting the results of the rational addiction model. Indeed, while the effects of past and future consumptions are often found to be significantly positive in the literature, the resulting intertemporal rates of substitution may take unlikely values. All in all, a rule of thumb would be to accept the assumption of rational addiction also based on a "reasonable" rate.[2]

[2] Remember the assumption in the rational addiction model that the intertemporal rate of substitution is equal to the interest rate of the economy. Arbitrarily, one can consider that a plausible rate should range between 0% and 25%. For instance, Becker (1996, p.103) reports a rate of 15% from applying the model to the consumption of cigarettes, arguing that it is a "quite reasonable" value.

3. Modeling and estimation

3.1. Notations

Unless explicitly stated, the following notations will be used all throughout the rest of our study. In addition to the subscripts i and t which identify respectively the household and the period, we also consider a subscript v which is related to a specific car owned by i at date t. These three subscripts are used all together to index the following variables:

- KM: the annual mileage converted into kilometers;
- FE: the average fuel efficiency in kilometers per liter;
- DP: the price for one liter of diesel oil in constant (2000) Euros;
- PP: the price for one liter of premium-petrol in constant (2000) Euros;
- FOC: the fuel operating cost per 100 kilometers. It is defined as $FOC_{ivt} = 100 \times (FP_{ivt}/FE_{ivt})$, where FP stands here for the price of the appropriate type of fuel (DP or PP);
- AD: the age of the car if it is diesel-powered;
- AP: the age of the car if it is petrol-powered.

Additional variables that describe the characteristics of the household will also be used. They are detailed in the next subsection.

3.2. The econometric model

The annual mileage of a car v that is owned by household i at date t is modeled as:

$$KM_{ivt} = \sum_s \beta_{0s} \mathbb{1}(R_{it} = s) + \beta_1 FOC_{ivt} + \beta_2 AD_{ivt} + \beta_3 AP_{ivt} + \varepsilon_{ivt}. \tag{11}$$

The error term ε_{ivt} is assumed to be drawn from a zero-mean normal distribution. The model intercept β_0 is here differentiated according to the household residential location: either Paris city ($R_{it} = 1$), or the inner suburbs of Paris ($R_{it} = 2$), or the outer suburbs of Paris ($R_{it} = 3$), or the Provinces ($R_{it} = 4$). The automobility of household i at date t is obtained by totalizing the annual mileages of the cars it owns on this date. Thus aggregated, the following model emerges:

$$\begin{aligned} KM_{it} = \sum_v KM_{ivt} &= \sum_s \beta_{0s} \mathbb{1}(R_{it} = s) NC_{it} + \beta_1 \sum_v FOC_{ivt} \\ &\quad + \beta_2 \sum_v AD_{ivt} + \beta_3 \sum_v AP_{ivt} + \sum_v \varepsilon_{ivt}, \end{aligned} \tag{12}$$

where NC refers to the number of cars. The previous specification is enlarged by introducing additional variables to allow for a better control of household heterogeneity: the household annual income in constant (2000) Euros, three dummy variables describing the age class of the household head ([18-39], [40-65], >65), the number of adults (except the head), the number of adults in employment, the number of adult women, the number of driving-license holders, and the number of children in the household. Finally, according to the type of addiction model – myopic or rational – to be estimated, the specification also includes the past and future household automobility ($KM_{t\pm1}$) as covariates.

3.3. Selectivity, heteroscedasticity and endogeneity

The addiction models require the dependent variable not be censored. In fact, the survey from which the data are drawn contains households that do not own cars. The annual mileage for these non-motorized households is zero, corresponding in microeconomics to a corner solution. The automobility models have been estimated using the subsample of households that declared to own at least one car in 2000. However, excluding the non-motorized households may result in a sample selection problem. This issue has been controlled by applying a two-step estimation procedure (Heckman 1979). In a first step, a dichotomous Probit model has been estimated to explain household car ownership. Then, the results from this so-called "selection model" have been used to estimate the current individual inverse Mills ratios λ_{it}, say $\hat{\lambda}_{it}$. The latter has in turn been introduced as covariate into the household mileage equation (12), which has been estimated using the subsample of car-owner households. This corrects for the potential selection bias by capturing the correlation in the error terms between the ownership-based selection and the automobility models. Testing for selection bias is easily carried out by checking whether the estimated coefficient that weighs $\hat{\lambda}_{it}$, say $\hat{\beta}_{\hat{\lambda}}$, is statistically different from zero.

This correction method of sample selection is not without some difficulties regarding inference. Actually, the introduction of $\hat{\lambda}_{it}$ into the automobility model generates heteroscedasticity, as it makes the variance of errors in (12) depend on the individual covariates used in the ownership Probit model (Heckman 1979). Correcting the sample selection is not the only reason why heteroscedasticity has to be taken into account. The structure of the proposed model is also a source. Indeed, the summation of car mileages to compute household automobility is likely to produce heteroscedasticity, related to the car ownership level. Thus, a robust estimation method allowing for a general form of heteroscedasticity should be applied.

By involving simultaneously both the lagged and the forwarded dependent variables as covariates, the dynamic specification of the rational addiction model makes them necessarily endogenous, even assuming the serial independence of individual errors. In addition, the errors are likely to be serially correlated due to an unobservable time-invariant household-specific factor η_i assuming that $\sum_v \varepsilon_{ivt} = \varepsilon_{it} = \eta_i + u_{it}$. Therefore, $KM_{it\pm1}$ and ε_{it} are correlated variables, and estimating the automobility models by means of ordinary least squares would yield biased estimates.

3.4. Estimation strategy and tests

A solution resides in turning to estimators that use instrumental variables. Among those that exist, the 2SLS estimator has almost but not all the desired properties. Although convergent, it is not consistent in the presence of heteroscedastic error terms.

It may however be used to test for existence of heteroscedasticity (Breusch and Pagan 1979). If the test rejects the homoscedasticity assumption, the Generalized Method of Moments (GMM hereafter) should then be applied (Hansen 1982). However, a condition for applying the GMM is to use a set of "good" instruments. They are required to be orthogonal to the estimation residuals and sufficiently correlated with the endogenous variables to be instrumented. Both properties have therefore to be examined. To that extent, the tests proposed by Hansen (1982) and Bound et al. (1995, BJB hereafter) are implemented. The readers are referred to Baum et al. (2003) for a detailed presentation of these methods.

4. Data and descriptive statistics

4.1. Data source

Data are drawn from the French "Car Fleet"[3] panel survey, which is achieved annually since the mid 1980s by the private pooling institute TNS-Sofres[4]. The survey aspires to a better knowledge of several dimensions of automobile demand in France, especially car ownership and use. It depicts with a great level of detail many of the attributes of the cars owned by the households, as well as many of the household characteristics. A nationally representative sample of 10,000 households is surveyed each year. The panel is rotating: about one third of the sample is renewed each year. Such a methodology allows for a longitudinal follow-up of some households for at least 3 years. In the present paper, we focus on households that were surveyed over the period 1999-2001, and we estimate the addiction models for $t = 2000$.

4.2. Descriptive statistics

We have identified 3010 households continuously present in the 1999, 2000 and 2001 waves of the survey. On annual averages, slightly less than 20 percent of them have no car, about 50 percent have one car, slightly more than 25 percent have two cars and about 5 percent have three cars or more.

The average automobility of households is monotonically decreasing over the covered period, from 15,610 kilometers in 1999 down to 14,826 kilometers in 2001. Excluding non-motorized households to cancel out the decision related to car ownership, we observe the same decreasing trend: the average household mileage also declines monotonically from 19,279 kilometers to 18,189 kilometers over the period. In the Appendix, Table A1 reports the annual descriptive statistics related to the characteristics of the sampled households.

In 1999, the households in the panel report a total of 3552 cars. There is a total of 3576 cars in 2000 and a total of 3605 cars in 2001. Based on this sample, Table A2 in the Appendix provides the descriptive statistics of the car attributes and mileages. In 2000, the average car is almost 6.8 years old. According to the type of engine, petrol-powered cars are about two years older on average than diesel-powered cars. This

[3]"Car Fleet" is the literal translation from French of the original name of the survey, "Parc Automobile".
[4]"Sofres" is the acronym for "Société Française d'Enquête par Sondages".

difference results from the very active dieselization trend in the French car fleet (Hivert 1999). In 1980, diesel cars represented less than 5 percent of the total fleet in France. This share has continuously increased to reach about 15 percent in 1990, 30 percent in 1995, 35 percent in 1999 and 40 percent in 2001[5]. In accordance with these figures, the proportion of diesel cars is also increasing in our data, from 35 percent in 1999 to 38 percent in 2001. Dieselization partially explains the improvement over time in the average energy efficiency of vehicles, since diesel cars consume less fuel on average than petrol cars of about 0.9 liters per 100 kilometers (Table A2). It also derives from the improvement in the fuel efficiency for both types of car over time: globally in the data, the average vehicle consumed 7.33 liters of fuel per 100 kilometers in 2001 to 7.44 liters initially in 1999.

After a period of low fuel prices during the 1990s in France, the year 2000 marked an episode of significant rise: in 1999, due to the decision of various oil-producing countries (including OPEC) to limit the production, the price of the crude oil barrel has soared. On annual averages, the price per liter of premium-petrol in France raised from €0.98 in 1999 to €1.14 in 2000 (from €0.69 to €0.85 for diesel-oil). But this increase has been short-lived, because during 2000, the production of oil increased again, resulting in a decline in fuel prices for the following year: in 2001, the price for one liter of premium-petrol dropped to €1.09 (€0.80 for diesel-oil). However, the fuel price trend over 1999-2001 still represents an increase for both premium-petrol (+11%) and diesel-oil (+16%) (Table A3, in the Appendix).

These differences in fuel price and energy efficiency partially explain the more intensive use of diesel cars. These have covered 17,085 km on average in 2000 to "only" 10,412 km for petrol cars. Between 1999 and 2001, average mileage decreased by 1600 km and 840 km for diesel and petrol cars respectively (Table A2). Thus, the decrease has been higher for diesel-powered cars than for petrol-powered cars. One reason is that the diesel-oil price per liter has increased faster than the premium petrol price.

5. Results

In the Appendix, Table A4 shows the estimates of the selection model, which is the first stage of our modeling approach. It simply models the household probability to own at least one car in 2000. As mentioned earlier, these estimates are used to compute the vector of individual correction factors $\hat{\lambda}$, which is introduced into the automobility model to control for selection. The estimates for addiction models are reported in Table 1. In this section, the myopic and the rational addiction models are compared so as to draw conclusions about the intertemporal dynamics of household automobility demand. Then, we mainly focus on the fuel cost and income effects, and derive the related elasticities of household car use. But first of all, we examine how the GMM estimations has performed.

[5]This phenomenon has even continued at the same pace during the 2000s: this proportion was about 50% in 2005 and 55% in 2008.

Table 1: Estimates of the myopic and rational addiction models applied to household automobility

Addiction Model	Myopic	Rational
Covariates	Coefficients	Coefficients
Dynamics		
Past automobility (KM_{it-1})	0.307^{***}	0.346^{***}
Future automobility (KM_{it+1})	–	0.295^{***}
Economic factors		
Fuel operating cost per 100 km $(\sum_v FOC_{ivt})$	-362.68^{***}	-223.29^{**}
Annual income (thousands of cst. 2000€)	87.37^{***}	46.37^{**}
Number of cars (NC_{it}) for households living in:		
Paris-city $(R_{it}=1)$	8813.36^{***}	5514.74^{***}
the inner suburbs of Paris $(R_{it}=2)$	8540.45^{***}	4888.76^{***}
the outer suburbs of Paris $(R_{it}=3)$	10810.79^{***}	6310.44^{***}
the Provinces $(R_{it}=4)$	11038.71^{***}	6189.06^{***}
Age of cars:		
Diesel cars $(\sum_v AD_{ivt})$	-24.75	-12.39
Petrol cars $(\sum_v AP_{ivt})$	-191.68^{***}	-104.05^{**}
Household characteristics		
Number of driving license holders	2138.45^{***}	1324.65^{**}
Number of adults (except the household head)	510.27	409.90
Number of employed persons	815.36^{**}	286.32
Number of women	-2041.94^{***}	-1158.26^{**}
Number of children	-174.64	-297.28
Age of the household head (ref: [18-40[)		
[40-65[	-1617.14^{***}	-1376.77^{**}
$\geq$65	-2648.16^{***}	-1608.01^{**}
Selection correction factor $\hat{\lambda}$	2430.34	1555.84
Intercept	-1210.78	-954.01

Significance levels: *** 1%; ** 5%; * 10%. Table continued on next page.

5.1. *Fitting properties and selectivity*

Both myopic and rational addiction models present good fitting properties on our disaggregate data. The R^2 statistics are respectively 0.58 and 0.67, and the Fisher statistics show that the set of explanatory variables is relevant to explain the dynamics of household automobility. The Breusch-Pagan statistic after estimating the models by 2SLS rejects the homoscedasticity assumption, and justifies resorting to the GMM estimator as IV technique.

The instruments that were used to implement the GMM are the set of current exogenous covariates (the "included" instruments) and a set of past and future household characteristics (the "excluded" instruments). In both models, the Hansen test cannot

Table 1: Estimates of the myopic and rational addiction models applied to household automobility (continued from previous page)

Addiction Model	Myopic	Rational
Intertemporal rate of substitution (ρ)	$+\infty$	17.04%
R^2	0.58	0.67
Fisher	$F(19,2611)$: 82.6 (0.00)	$F(20,2610)$: 115.5 (0.00)
Breusch–Pagan, after 2SLS	$\chi^2(40)$: 777.0 (0.00)	$\chi^2(40)$: 878.8 (0.00)
Hansen	$\chi^2(21)$: 30.46 (0.08)	$\chi^2(20)$: 23.22 (0.28)
BJB	$F(22,2590)$: KM_{t-1} : 3.80 (0.00)	$F(22,2590)$: KM_{t-1} : 3.80 (0.00) KM_{t+1} : 4.51 (0.00)
Anderson-Rubin	$\chi^2(22)$: 40.47 (0.01)	$\chi^2(22)$: 40.47 (0.01)

Notes: p-values in parentheses. Estimation using the subsample of 2631 households which described at least one car in 2000. Dependent variable: KM in 2000 (Section 3). GMM estimation (2 covariates related to age- and type-ambiguous cars not reported).

reject the null hypothesis that residuals and instruments are orthogonal. Moreover, the BJB test concludes to acceptance of the alternative hypothesis that excluded instruments are jointly significant in explaining the endogenous covariates. This is supported by the Anderson-Rubin test,[6] which suggests that the endogenous covariates are not too weakly explained by the "excluded" instruments.

Both addiction models agree not to conclude to significance of the correction factor $\hat{\lambda}$. Indeed, the null hypothesis $H0 : \beta_{\hat{\lambda}} = 0$ cannot be rejected at the 5 percent level, meaning that the selection of car owner households in 2000 to estimate the automobility models has not been a significant source of bias. Finding no evidence for selection bias should not be surprising here. It only means that the ownership and automobility models are specified in such a way that their errors are not significantly correlated. In other words, given that the explanatory variables used in the household ownership model are also included in the automobility models, the unobserved factors impacting ownership are found not to influence significantly household car use.[7]

[6] Anderson and Rubin (1949).

[7] For example, variables as car parking facilities are likely to impact household car ownership. But while they are captured by the error term in the ownership model, there is no reason that such variables also determine household car use, resulting in the non significance of the selection correction factor. At the

Table 2: Short and long-run elasticities of household automobility with respect to the fuel operating cost and income

Addiction model	Myopic	Rational
Fuel operating cost		
Short run	-0.22 $[-0.34; -0.10]$	-0.23 $[-0.41; -0.05]$
Long run	-0.31 $[-0.47; -0.16]$	-0.37 $[-0.72; -0.08]$
Income		
Short run	$+0.11$ $[+0.06; +0.16]$	$+0.10$ $[+0.03; +0.16]$
Long run	$+0.16$ $[+0.09; +0.23]$	$+0.16$ $[+0.06; +0.29]$

Notes: 95% confidence intervals in brackets.

5.2. Addiction and intertemporal rate of substitution

While the results substantiate the addiction hypothesis regarding household automobility behavior, the rational addiction model emerges as the most relevant to describe the type of car use dependence captured by the data. Indeed, the myopic model confirms the significant effect of households' past annual mileage on their current automobility. But on the other hand, the rational model rejects the behavioral myopia assumption, as the parameter that weighs the forwarded annual mileage is also statistically significant. Therefore, households are forward-looking agents in setting their automobility demand. Furthermore, the rational addiction model yields an intertemporal rate of substitution of about 17 percent, which is a rather plausible value.[2]

5.3. Cost and income elasticities of automobility

The estimates related to the fuel operating cost have the expected negative signs in both models, but their levels of significance slightly differ. It is significant at the 1 percent level in the myopic model while it is just significant at the 5 percent level in the rational model.

Elasticity measures of household automobility with respect to fuel operating cost are reported in Table 2. The myopic and rational addiction models agree upon measuring the short-run cost-elasticity at -0.22. Because of a larger intertemporal perspective in the rational addiction model, the long-run cost-elasticity is higher (-0.37) than in the myopic model (-0.31). A raise by (constant 2000) €1 in the cost to achieve 100 km entails an estimated decrease in the annual mileage per car by 380 km in the short run, and 623 km in the long run (Table 3).

Estimating cost-sensitivities of car use has been the topic of many earlier works. To cite a few, such figures were estimated and discussed in Hensher et al. (1990), Oum et al. (1992), Eltony (1993), Rouwendal (1996), Johansson and Schipper (1997), and

opposite, household income is shown to determine significantly both car ownership and use. If it has not been included in the explanatory variables, the selection correction factor would have been significant.

Table 3: Short and long-run marginal effects on household automobility

Horizon	Short run	Long run
Effect on household automobility induced by:		
• a (constant 2000) €1000 raise in the household annual income	+79 km	+131 km
	[+20; +125]	[+39; +223]
• a (constant 2000) €1 raise in the fuel cost per 100 km, per car	−380 km	−623 km
	[−676; −79]	[−1194; −138]

Notes: Evaluation from the rational addiction model (Table 1). 95% confidence intervals in brackets.

Berri et al. (2005). Graham and Glaister (2002) collected many existing results in the literature dealing with car use sensitivities to fuel price, which can be expected to be close to our fuel cost-elasticities. In their survey, the work of Goodwin (1992) is mentioned: based on four elasticities drawn from empirical studies in the 1980s, the author reported an average fuel price sensitivity of automobile traffic of −0.16 for the short run, and −0.33 for the long run. Goodwin et al. (2004) updated these meta-analytic results using empirical works published in the 1990s and in the early 2000s. They reported an average sensitivity of car use with respect to fuel price of −0.10 for the short-term and −0.30 for the long-term.

In our application, the most relevant model to be compared with the literature is probably the myopic addiction model, since short- and long-run elasticities are usually derived from first-order autoregressive specifications. In this model, the long-run fuel cost-elasticity of household automobility, estimated at −0.31, thus emerges as a very plausible value. Relatively, the short-run elasticity obtained from this model (−0.22) could seem high, meaning a fast convergence to the long-term equilibrium. In other words, French households would adapt quickly their automobility to a change in the fuel operating cost. This conclusion is supported by Graham and Glaister (2002, p.22, fig.1). Indeed, the authors reported price-elasticities of the demand for gasoline for a set of western countries: comparatively, France presents one of the highest sensitivities in the short run and one of the lowest in the long run. The short-long ratio is about 3/4, while it is clearly below 0.5 for the other comparable countries (including Germany, United Kingdom, Austria and Canada).

Table 4 reports the sensitivity of car annual mileage to the fuel price, by type of engine. The elasticity of annual mileage for petrol-powered cars with respect to premium-petrol price is estimated at −0.32 in the short run and at −0.52 in the long run. Regarding diesel-powered cars, these elasticities with respect to the diesel-oil price are −0.13 and −0.21 respectively.[8] Thus, the use of petrol cars is about 2.5 times more sensitive to fuel price variations than diesel cars, both in the short and the long runs. These

[8]Example: in 2000, the fuel efficiency of the average diesel car was 14.71 km per liter of diesel-oil, the average mileage for this type of car was 17,085 km (Table A2), and the price for one liter of diesel-oil was €0.8461 (Table A3). Moreover, the long-term marginal effect of the fuel operating cost per 100 km on automobility is estimated at −623 km by car (Table 3). For diesel cars, the long-run elasticity of mileage to the diesel-oil price is evaluated at: $(-623/0.1471) \times (0.8461/17,085) = -0.21$.

Table 4: Elasticities of annual mileage of cars with respect to fuel prices

Horizon	Car type (fuel used)	Elasticity
Short-run	Diesel car (diesel-oil)	-0.13 $[-0.19; -0.10]$
	Petrol car (premium-petrol)	-0.32 $[-0.46; -0.25]$
Short-run	Diesel car (diesel-oil)	-0.21 $[-0.40; -0.14]$
	Petrol car (premium-petrol)	-0.52 $[-1.03; -0.36]$

Notes: Elasticities evaluated at the average petrol and diesel cars in 2000, using the estimates of the rational addiction model and the fuel prices in 2000 (see Footnote 8 for details). 95% confidence intervals in brackets.

short-run fuel price elasticities of car use are very close to those recently published by Calvet and Marical (2012, Tab. 1). Based on the 2006 French family budget survey, the figures reported by the authors are -0.11 for diesel-powered cars, and -0.35 for petrol-powered cars. However, these estimates are found not to be significant, whereas they are in our study.

The estimated coefficient that pertains to the household annual income is significant and has the expected positive sign in both addiction models. Table 2 also reports the short- and long-run elasticities of households' automobility with respect to their income. Whichever addiction model is considered, these elasticities take similar values: about $+0.10$ in the short run and about $+0.16$ in the long run. Using the results from the rational addiction model, an increase by (constant 2000) €1000 in the household annual income yields an increase in its automobility by about 79 km in the short run, and 131 km in the long run (Table 3). In Hensher et al. (1990), the income-elasticities of car use for households living in the Sydney urban area ranged from $+0.05$ to $+0.14$ according to the car ownership level. Mentioned for comparison in their article, Greene and Hu (1984) and Mannering and Winston (1985) respectively estimated this elasticity at $+0.13$ and $+0.11$ for the United States. Thus, our elasticity figures do not differ much from these references. Nevertheless, since income is a key factor of household car ownership, income-elasticities of automobility should vary widely depending on whether the level of car equipment is held constant, as in our study, or not.[9]

6. Conclusions

This article focuses on modeling the annual mileage covered by households with their personal cars, that is, their "automobility". It sheds new light on the car dependence issue. The results that are presented put the emphasis on the rational addiction

[9] For example, Collet (2012) reports an income-elasticity of household automobility in France of about $+0.5$, but applying a static model that does not control for the household car ownership level.

model proposed by Becker et al. (1994), which had not been applied to automobile data so far. Uncommon within our context, this model lives up to expectations when applied to describe the empirical automobility behavior of French households in 2000. Indeed, the assumption of addiction to car use is not statistically rejected. Therefore, assertions that relate car use to an addictive consumption in the transportation literature are reinforced by the microeconomic point of view. Then, the rational version of the addiction model proves to be more relevant than the myopic version. Indeed, both past and future household car use are significant in explaining current automobility in the rational addiction model. Moreover, the intertemporal rate of substitution is estimated at 17 percent, which is a likely value. Such results show that the household behavior is consistent with a theoretical intertemporal optimization scheme. This conclusion stands our work apart from earlier dynamic studies, which may have missed an important point in explaining car use demand. Indeed, models based on a first-order autoregressive specification are useful for deriving short and long-run elasticities, but they also require the individuals to be myopic as it regards the future. Nonetheless, the myopic model is also reported to make comparisons with other studies.

In France, the fuel operating cost– and income–elasticities of household automobility derived from the rational addiction model coincide with expectations. The respective estimations are -0.23 and $+0.10$ for the short run, -0.37 and $+0.16$ for the long run. These figures do not diverge from existing results that were reported in the transportation literature. According to the type, petrol cars are more sensitive than diesel cars to a change in fuel price. For diesel cars, the elasticity of annual mileage with respect to the diesel-oil price is estimated at -0.13 in the short run, while that for petrol cars with respect to the premium-petrol price is measured at -0.32. The long-run elasticities are found to be about 1.6 times higher. Our elasticity results are sensible whichever addiction model is applied, myopic or rational. As it regards the latter, it strengthens our recommendation to apply it when data are available, in order to draw further conclusions related to car dependence and intertemporal substitution.

Appendix

Table A1: Descriptive statistics of household characteristics

Year	1999		2000		2001	
Variable	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Number of cars	1.18	0.82	1.19	0.80	1.20	0.82
Number of adults	1.86	0.74	1.86	0.74	1.87	0.75
Number of employed adults	1.00	0.85	0.98	0.85	0.98	0.86
Number of women	0.98	0.48	0.98	0.48	0.98	0.48
Number of children	0.52	0.93	0.50	0.91	0.49	0.90
Number of licenses	1.55	0.82	1.56	0.81	1.57	0.81
Annual income (thousands of constant 2000€)	23.23	13.77	23.82	13.95	27.28	14.15
Age of the household head:						
< 40	0.34	0.47	0.31	0.46	0.29	0.45
$[40; 65]$	0.42	0.49	0.42	0.49	0.42	0.49
> 65	0.24	0.43	0.27	0.44	0.29	0.45
Residential location:						
Paris-city	0.05	0.22	0.05	0.22	0.05	0.22
Inner suburbs of Paris	0.06	0.24	0.06	0.24	0.06	0.24
Outer suburbs of Paris	0.07	0.25	0.07	0.25	0.07	0.25
The Provinces	0.82	0.38	0.82	0.38	0.82	0.38
Automobility (in km):						
(motorized households only)	19,279	12,759	18,563	12,313	18,189	12,576
(all the households)	15,610	13,752	15,193	13,240	14,826	13,371

Source: 1999–2001 French Car Fleet panel (3010 households).

Table A2: Descriptive statistics of car characteristics

Year	1999		2000		2001	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Repartition						
Diesel cars	0.34	0.23	0.36	0.23	0.38	0.24
Petrol cars	0.64	0.23	0.63	0.23	0.61	0.24
Mileage (in km)						
Diesel cars	17786	9014	17085	9099	16187	8662
Petrol cars	11001	6564	10412	6138	10157	6172
Age (in years)						
Diesel cars	5.19	4.01	5.52	4.28	5.48	4.38
Petrol cars	7.22	5.70	7.50	5.86	7.56	5.99
Energy consumption (L/100 km)						
Diesel cars	6.82	1.29	6.80	1.49	6.74	1.35
Petrol cars	7.74	1.63	7.72	1.58	7.67	1.56
Harmonic mean of the vehicle fuel efficiency (km/L)						
Diesel cars	14.66		14.71		14.84	
Petrol cars	12.91		12.95		13.03	
Number of observations	3552 cars		3576 cars		3605 cars	

Source: 1999-2001 French Car Fleet panel. Notes: All the personal cars described by the households of the panel. Statistics for fuel-ambiguous cars (2% of the car sample for 1999, 1% for 2000 and 2001) not reported.

Table A3: Fuel prices at filling stations in France

Year	1999	2000	2001
Diesel-oil (€/Liter)	0.6890	0.8461	0.7958
Premium-petrol (€/Liter)	0.9825	1.1380	1.0877

Source: Calculations from the yearbooks of the French professional comity of oils.

Table A4: Selection model estimates - Car ownership Probit model

Covariates	Coefficients	t–values
Household annual income (thousands of constant 2000€)	1.42	4.91
Age of the household head (reference: [40 ; 65[)		
[18;40[	−0.10	−0.80
> 65	0.22	2.19
Household location (reference: Paris–city)		
Inner suburbs of Paris	0.68	3.81
Outer suburbs of Paris	1.64	8.10
The Provinces	1.65	11.13
Number of driving license owners	1.50	20.22
Number of adults (except the head)	0.07	0.91
Number of employed persons	0.11	1.43
Number of women	−0.36	−4.05
Number of children	0.15	2.44
Intercept	−2.63	−12.99

Notes: Probit estimation for wave 2000 of the panel, 3010 households. Dependent variable: $Y_{it} = 1$ if the household owned at least one car (2631 cases), 0 otherwise (379 cases).

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